

Prospects at Future B Factories

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1 Introduction

The present flavour physics landscape has been reshaped in the last decade by the *BABAR* and Belle B Factory experiments and by D0 and CDF at the Tevatron, and is now evolving at LHC. The CKM paradigm has been challenged with increasing precision, but is standing all tests so far.

The projects Super B and SuperKEKB for two next-generation asymmetric e^+e^- flavor factories aim at collecting data samples of $50 - 75 \text{ ab}^{-1}$, with therefore a $\times 100$ increase in the statistics collected by *BABAR* and Belle¹. The Belle II experiment built at the SuperKEKB facility in Japan is expected to start taking data in 2016, and to collect a sample of 50 ab^{-1} by 2021. At that time the LHC experiments will have fully explored the energy scale $\mathcal{O}(1\text{TeV})$ they are designed to have access to, and the High Energy Physics community will face one of two possible situations. In case signals of New Physics (NP) are found at the LHC, Belle II could study its flavor structure, measure the flavor couplings and search for still heavier mass states. Alternatively, the NP energy scale could lie above the direct reach of the LHC – indeed, model-dependent direct searches performed with the limited data samples collected to date have found no evidence of physics beyond the Standard Model, SM. In such a scenario Belle II can look for indirect NP signals, understand where they may come from, and exclude regions in the multi-dimensional parameter space of NP models up to $\Lambda \simeq 10\text{TeV}$ or more. In addition to probing energy scales higher than those accessible at the LHC via virtual processes, a Super Flavor Factory can, thanks to its clean e^+e^- environment, experimentally access several physics channels precluded to hadronic machines as LHC. Those channels include decays with neutrinos or many neutral particles in the final state, or whenever an inclusive analysis is required.

¹ At the time of writing these proceedings it was announced that the Super B project[1, 2] to be built at the Nicola Cabibbo Laboratory between Frascati and Rome, Italy, was shut down by the Italian Government due to funding problems. While the physics of mixing and mixing-related CP violation in the B system is clearly in common between the Belle II [3] and the Super B experiments, I will not further discuss the latter in the remainder of the present report.

2 Hunting for New Physics at a Super B Factory

Although there is general agreement that the SM can only be the low-energy manifestation of a more complete theory at a larger mass scale, a variety of NP models exist, with many non predicted parameters, including the New Physics mass scale Λ_{NP} . In this respect, the search for NP is a complex task which can only be accomplished with a multilateral approach, in which a high-luminosity B Factory will play a crucial role. A recent example of the potentiality of precision “low energy” measurements in constraining NP models was discussed at this Workshop and previously presented at the FPCP Conference [4] with the $B \rightarrow D^{(*)}\tau\nu$ decays. The *BABAR* data on the branching fractions for these decays (normalized to the corresponding $B \rightarrow D^{(*)}\ell\nu$ ones, with $\ell = e, \mu$ to reduce experimental uncertainties) disagree with the SM at the 3.4σ level. On the other hand, since there is no value of the ratio $\tan\beta/m_{H^\pm}$ that can simultaneously accommodate the $B \rightarrow D\tau\nu$ and the $B \rightarrow D^*\tau\nu$ measurements, these data also exclude the widely discussed type II two-Higgs-doublet model.

As demonstrated by the several hundred papers published by the B Factory experiments, a wide range of important measurements can be performed at the $\Upsilon(4S)$ resonance. Most of these are statistics-limited, and would therefore improve substantially with a data sample of 50 ab^{-1} . In many cases, large control samples can be used to further reduce systematic and theoretical errors. Control of the theoretical errors (e.g. those related to lattice calculations) is particularly relevant to fully exploit the statistical power of the experimental measurements. In the last few years the global fits of flavour data [5, 6] have at times highlighted imperfect agreement among some of the angles or sides of the Unitarity Triangle (UT), which is tempting to interpret as hints of physics beyond the Standard Model. These “tensions” were at the 3σ level or less, and have always been resolved as statistical fluctuations so far. These tests of the internal consistency of the SM will become significantly more stringent when the experimental errors are reduced. With 50 ab^{-1} a Super B Factory will also be able to substantially improve on the precision of the CKM Unitarity Triangle parameters. For example, the present error on the $\bar{\rho}$ and $\bar{\eta}$ parameters of the UT in a global fit where New Physics contributions are allowed (± 0.056 and ± 0.036 respectively), could be reduced to $\delta\bar{\rho} = 0.005$, $\delta\bar{\eta} = 0.005$. Such an improvement will be crucial for many NP searches with flavor, both in the B sector and elsewhere, *e.g.* in the Kaon sector.

The possibility to study a very large numbers of physical observables, and the correlations among them, is a particularly important tool to elucidate the nature of new physics, should deviations with respect to SM predictions be observed.

3 New Physics Contributions in $\Delta F = 1$ Processes

The measurement of $\sin 2\beta$ through mixing-induced CP violation in the decay $B^0 \rightarrow J/\psi K_s^0$, one of the theoretically cleanest measurements that can be made in flavour physics, was among the main motivation for building the current generations of B Factories, and its precise measurement (the present HFAG [7] average from *BABAR* and *Belle* is $\sin 2\beta = 0.665 \pm 0.023 \pm 0.010$) is indeed a great success of the factories. The precision on $\sin 2\beta$ will be further improved at a Super B Factory. After some 10 ab^{-1} the systematic error will dominate; the theoretical error from possible penguin contributions can instead be controlled to the desired precision using the $B^0 \rightarrow J/\psi \pi^0$ and $B^+ \rightarrow J/\psi K^+$ decay channels [8, 9]. The sine coefficient S_f in mixing-induced CP violation has the same CKM matrix coefficients in the Standard Model for the $b \rightarrow c\bar{c}s$, $b \rightarrow c\bar{c}d$, $b \rightarrow s\bar{s}s$ and $b \rightarrow d\bar{d}s$ modes. The latter three modes are loop-dominated processes and can receive sizable contributions from New Physics; it is therefore important to compare them with the reference value of $\sin 2\beta$ in $b \rightarrow c\bar{c}s$. This is especially relevant for some of the $b \rightarrow s\bar{s}s$ decay channels such as $B^0 \rightarrow \eta' K_s^0$, whose experimental signature and theoretical calculations are clean enough to allow a precise test. A summary of the most significant of these modes, comparing the precision at present and the one attainable at a Super B Factory is shown in Table 1.

Mode	Current Precision			Predicted Precision (75 ab^{-1})	
	Stat.	Syst.	ΔS_f	Stat.	Syst.
$B^0 \rightarrow J/\psi K_s^0$	0.022	0.010	0 ± 0.01	0.002	0.005
$\eta' K_s^0$	0.08	0.02	0.015 ± 0.015	0.006	0.005
$f_0 K_s^0$	0.18	0.04	0 ± 0.02	0.012	0.003
$K_s^0 K_s^0 K_s^0$	0.19	0.03	0.02 ± 0.01	0.015	0.020
ϕK_s^0	0.26	0.03	0.03 ± 0.02	0.020	0.005
$J/\psi \pi^0$	0.21	0.04		0.016	0.005

Table 1: Summary of current and predicted precision for the cleanest $b \rightarrow s\bar{s}s$ modes, compared to $B^0 \rightarrow J/\psi K_s^0$, from [10].

At this workshop we have seen very beautiful analyses by the LHCb experiment, which is clearly a competitor a high-luminosity B Factory will have to deal with. In general, the well-defined initial state and a more hermetic detector at an e^+e^- machine allow better tagging efficiency, better reconstruction of modes with many neutral particles and/or neutrinos in the final state, and in some cases a better control of systematic effects, thus counterbalancing the larger statistical power LHCb gets from the higher hadronic cross section. The high luminosity B Factories and LHCb can therefore produce complementary measurements to test the SM.

4 More Physics Opportunities

CP violation in mixing, predicted in the SM [11, 12] to be $\mathcal{O}(10^{-3})$, has been searched for at the B Factories using same-sign dilepton events in which both B mesons decay semileptonically. The search was conducted both inclusively and in events in which one of the B decays is at least partially reconstructed; the latter method trades some loss in statistical power with a better control of systematics. Still another variation of the method can be adopted, in which the semileptonic asymmetry A_{SL} is measured comparing mixed ($\ell^\pm K^\pm$) vs. unmixed ($\ell^\pm K^\mp$) events in which the flavour of one of the B mesons is tagged by a kaon. A preliminary results using the technique above was presented at this conference [13], yielding a value of A_{SL} consistent with the world average, but more precise. We are longing to see this analysis published.

Since the current A_{SL} measurements are already reaching the level of being limited by systematic uncertainties, even with the Super B Factory data sample it will require a lot of effort to push down the precision – this will presumably require a smart data-driven approach. But given that the SM prediction is “around the corner”, the potential reward of observing CP violation in the mixing in the B system is certainly worth the effort. In addition there is always the possibility that physics beyond the SM is at work, and CP violation in the mixing is sensitive to such effects [14, 15, 16].

A tantalizing 2.8σ effect of sidereal-time dependent CPT violation using dilepton events has been around for years [17], and it will be interesting to repeat such measurements with the Super B Factory data samples. Analogously, it would be very important to repeat with 50 ab^{-1} the new $BABAR$ measurement [18] which used $B^0\bar{B}^0 \rightarrow J/\psi K^0$, $\ell^\pm X^\mp \nu$ decays to perform a simultaneous test of T , CP and CPT violation without any a-priori assumptions.

Mixing-induced CP violation in $b \rightarrow s\gamma$ transitions is suppressed in the SM (*e.g.* $|S_{B^0 \rightarrow K_S^0 \pi^0 \gamma}| < 0.1$ even considering strong interaction uncertainties [19]) because the photons carry opposite polarisations when produced from b or \bar{b} decays. A high precision measurement of this decay mode is very sensitive to RH currents arising from NP. The current experimental world average error, $\delta S_{B^0 \rightarrow K_S^0 \pi^0 \gamma} = \pm 0.20$, dominated by the statistical uncertainty, can be reduced to ± 0.03 with 50 ab^{-1} . This mode, with three photons in the final state and the B decay vertex reconstructed by the $K_S^0 \rightarrow \pi^+ \pi^-$ decay constrained to the measured beam-spot position, can be efficiently measured only at an e^+e^- collider; similarly for other modes such as $B^0 \rightarrow K_S^0 \eta \gamma$ and $B^0 \rightarrow K_S^0 \phi \gamma$. Other ways of probing the photon polarization in $B^0 \rightarrow K_S^0 \pi^0 \gamma$ decays with very large data samples exist; an interesting example proposed in [20] involves using $\gamma \rightarrow e^+e^-$ conversions in the detector material. The distribution of the angle of the e^+e^- plane with respect to the plane in which the K_S^0 and γ lie depends on the photon left and right polarization amplitudes. In the same reference it is estimated that a 4 sigma effect could be detected with 50 ab^{-1} in case of maximal RH currents.

5 Summary

A very concise overview of the possibilities offered by high-luminosity B Factories in mixing and mixing-related CP violating processes in B decays was given. An exhaustive discussion of the (now stopped) Super B project can be found in [1, 10, 21, 22]; the Super B Technical Design report is undergoing final review and will be published shortly. The Belle II and SuperKEKB projects [3] are progressing well, and are on track for starting the data taking in 2016.

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